S26 Basic research on 6.x nm EUV generation by laser produced plasma

Tsukasa Hori, Tatsuya Yanagida, Hitoshi Nagano, Yasunori Wada, Soumagne Georg, Junichi Fujimoto*, Hakaru Mizoguchi*

e-mail : tsukasa_hori@komatsu.co.jp

Gigaphoton Inc.*

KOMATSU Ltd.

Nov. 08, 2011

KWDL11-537

Contents

- Introduction
- Basic research test rig
- 13.5 nm EUV experimental results on test rig
- 6.x nm EUV experiential results on test rig
- Conclusion
- Future work

Introduction

➢ Laser Produced Plasma EUV light source

			EUV	BEUV
Wavelength		nm	13.5	6.x
Target	material		Tin	Gd? Tb?
	Supply		Molten Tin by droplet	?
Drive Laser	Type		CO2	CO2? Solid state?
	wavelength	um	10.6	10.6? 1.06?
	Intensity for CE > 1%	W/cm^2	$> 10^{10}$	$> 10^{12}$?
Collecting Mirror	Multi layer structure		Mo/Si	Mo/B4C? La/B4C?

KOMATSU

LPP EUV Light Source

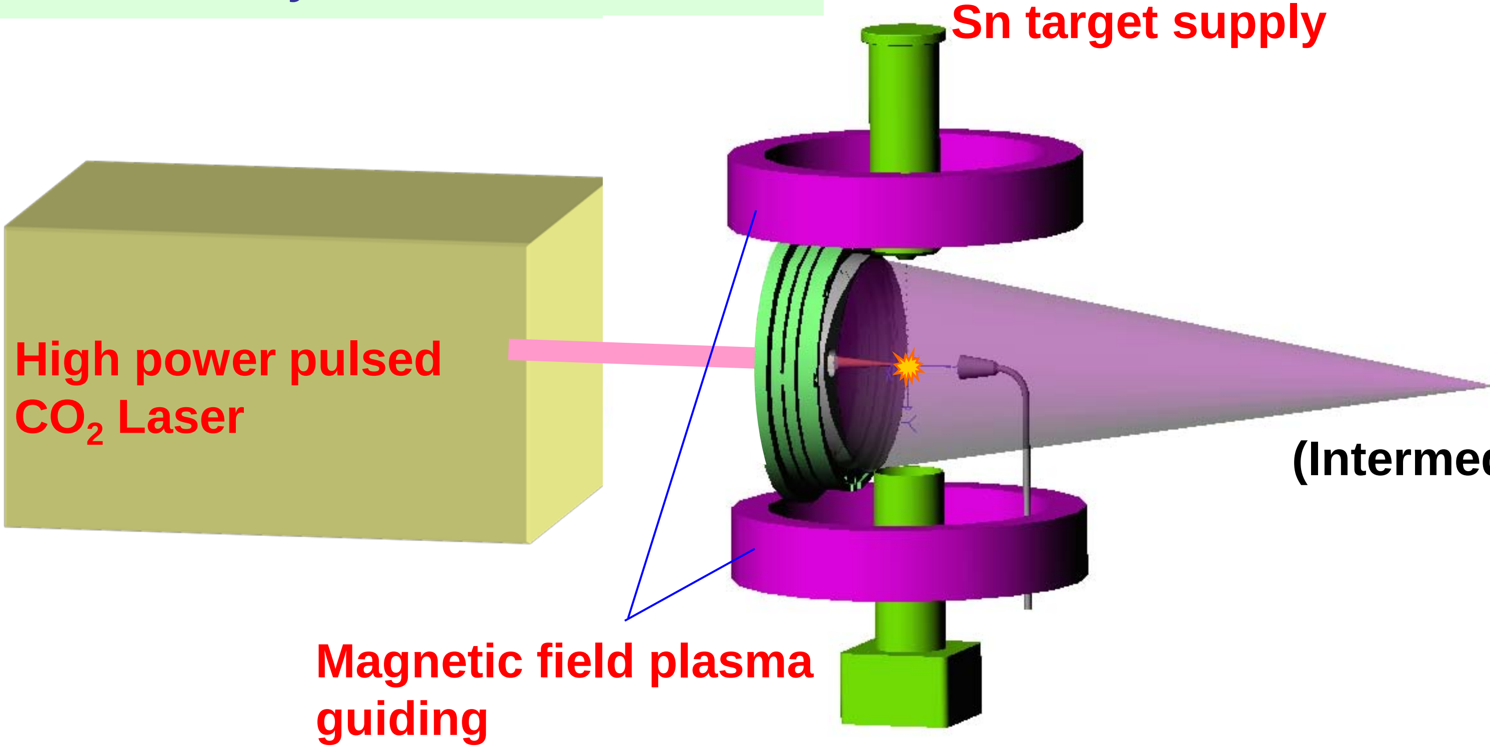
13.5nm

Requirements for HVM EUV source

- High EUV power
- Long collector mirror lifetime
- EUV Stability
- Low CoG / CoO
- Reliability,・・・

EUVA LPP concept

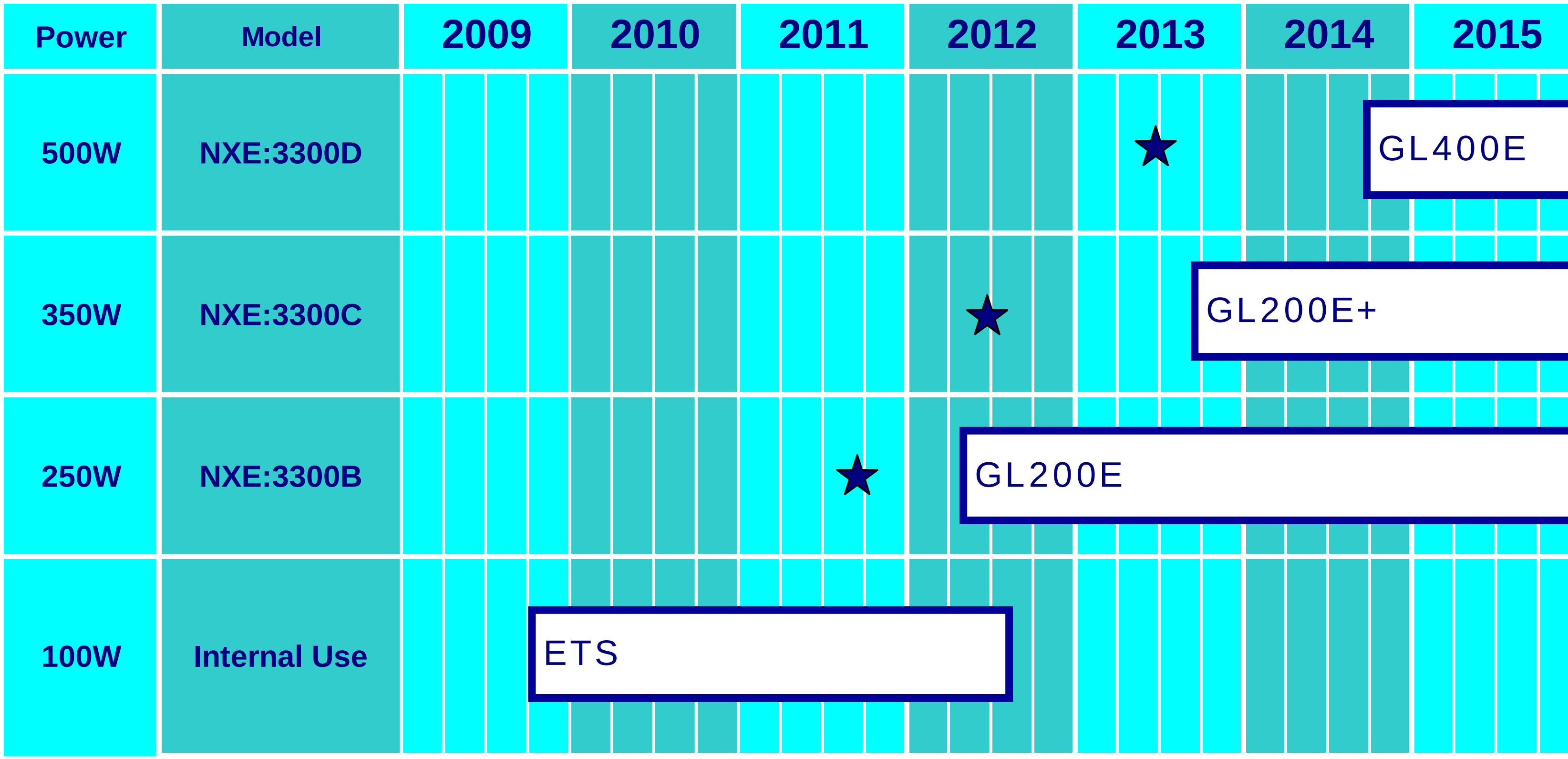
- CO_2 laser
- + Sn target
- + Magnetic field plasma guiding



KOMATSU

EUV Product Roadmap

13.5nm

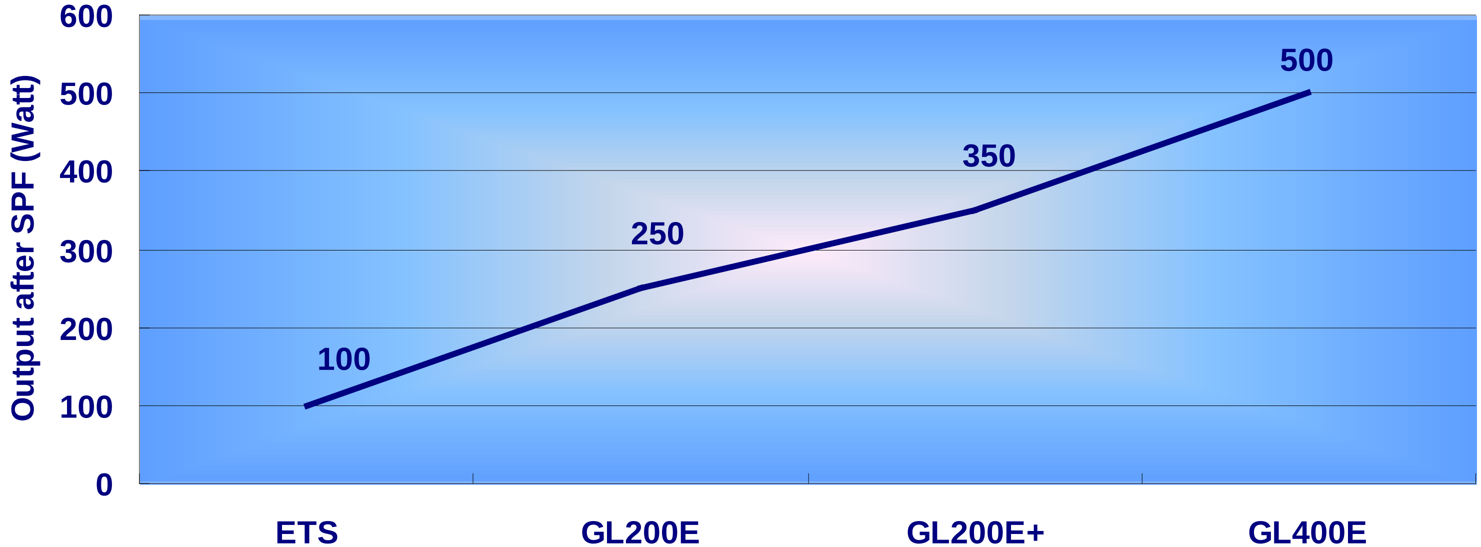


★ 1st source delivery

- GL200E will be delivered to scanner manufacture at Mid Y2011.

Clean Power Roadmap

13.5nm



EUV model		ETS	GL200E	GL200E+	GL400E
Drive laser power	kW	10	23	33	40
Conversion efficiency	%	3.0	5.0	5.0	6.0
C1 mirror collector angle	sr	5.5	5.5	5.5	5.5
efficiency*	%	74	74	74	74
C1 mirror reflectivity	%	(50)	57	57	57
Optical transmission	%	95	95	95	95
SPF (IR, DUV)	%	N/A**	62	62	62
Total EUV power (after SF	W	100	250	350	500

* Against hemisphere (Calculation base)
** w/o SPF

KOMATSU

Basic research test rig

- Same approach of 13.5 nm development for 6.x nm EUV feasibility study

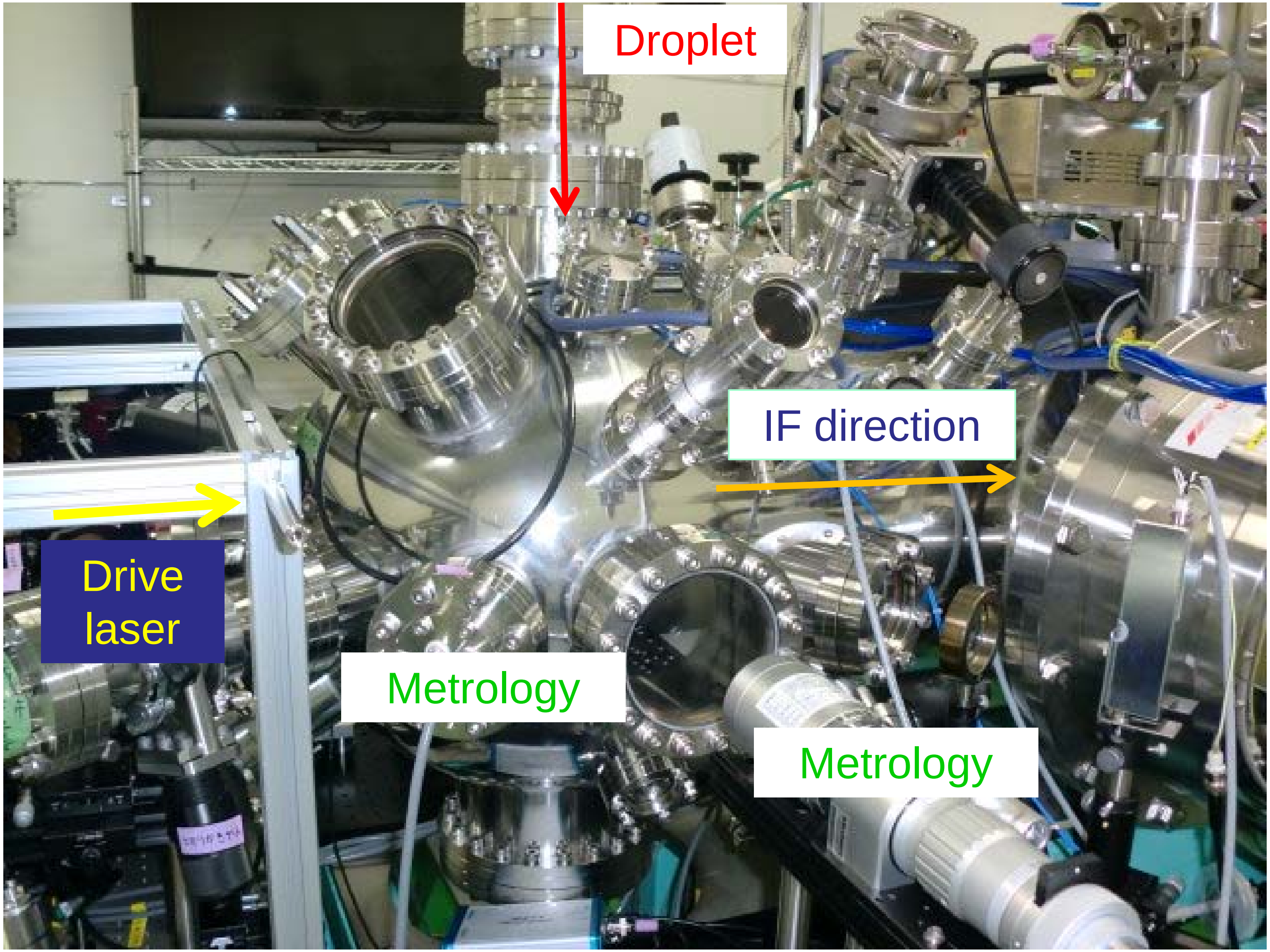
	Done for 13.56nm	To be done for 6.x nm
Target	Droplet generator improvement	Material selection State, structure optimization
Drive laser	Property optimization	Property selection wavelength, intensity
System	Shooting optimization for higher CE	Experimentally CE confirmation
Debris mitigation	Concept proof Mitigation effect confirmation	Mitigation effect confirmation

Basic Research Test Rig

- Compact but sufficient for verification

Component	HVM	Test rig
Droplet generator	100 kHz ~30 um	10Hz ~ 100 um
CO2 Laser	100 kHz 20 kW	10 Hz 2.7 W
Magnetic field	Applied	Applied
Collector mirror	Applied	Not applied (EUV sensors at mirror position)

Outlook



Metrology in test rig

13.5nm

6.x nm

	Method	Measured	13.5 nm	6.X nm
Fragments	Witness plates Shadow graph	Diameter Spatial distribution	OK	OK
neutrals	Laser induced Fluorescence (LIF)	Density Speed Spatial distribution	OK	To be applied
ions	Faraday cup	Density Spatial distribution	OK	OK
EUV light	Flying circus	Energy	OK	OK
CO_2 laser	Power meter	Transparent of CO_2 laser Reflect of CO_2 laser	OK	OK

13.5 nm EUV experimental results on test rig

13.5 nm study results review on test rig

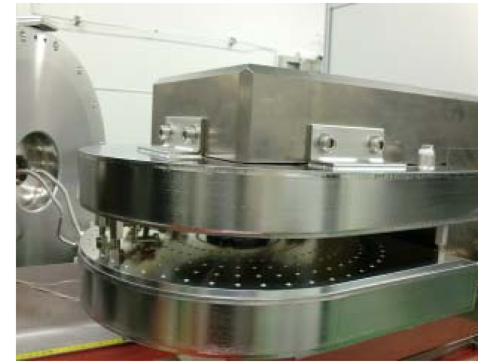
Study for Sn mitigation

Study for improving conversion Efficiency

Sn Mitigation : Experimental Setup

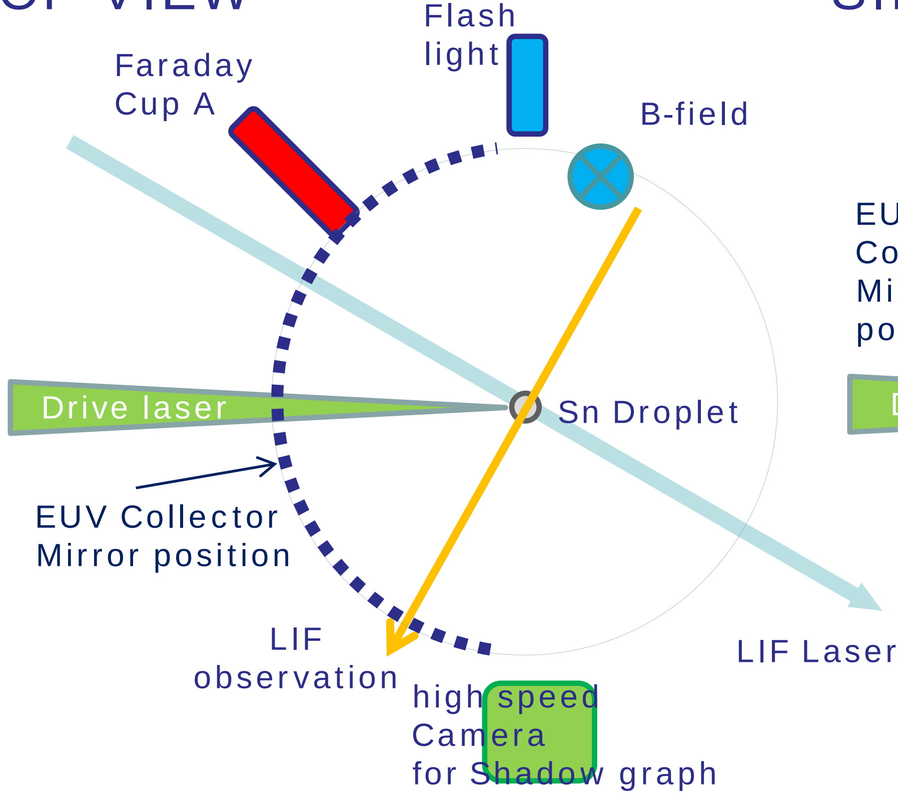
13.5nm

Fragment	Shadow graph
Atom	LIF (Laser Induced Fluorescence)
Ion	Faraday cup A : Perpendicular to B Faraday cup B : Parallel to B

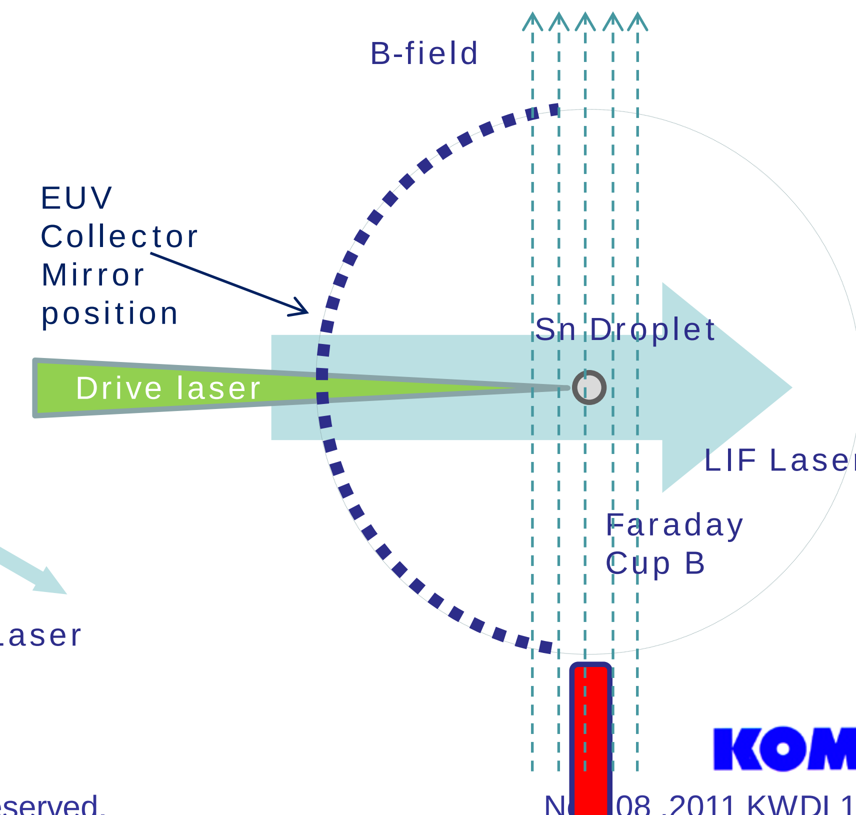


Magnet

TOP VIEW



SIDE VIEW

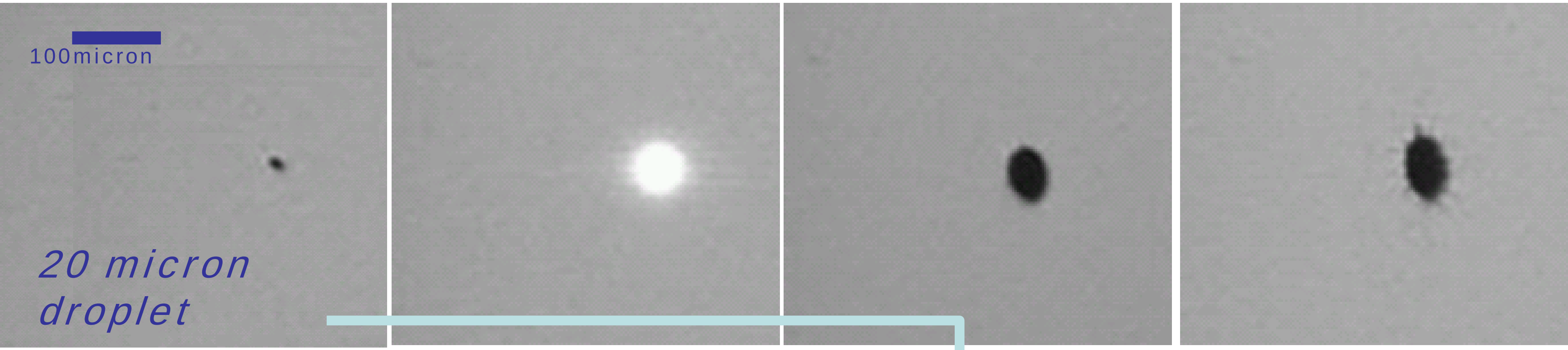


Sn Fragment Measurement by Shadow Graph 13.5nm

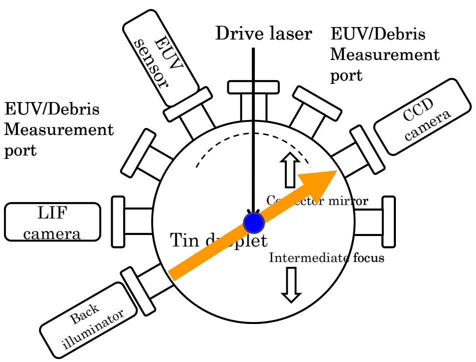
Proper pre-pulse condition

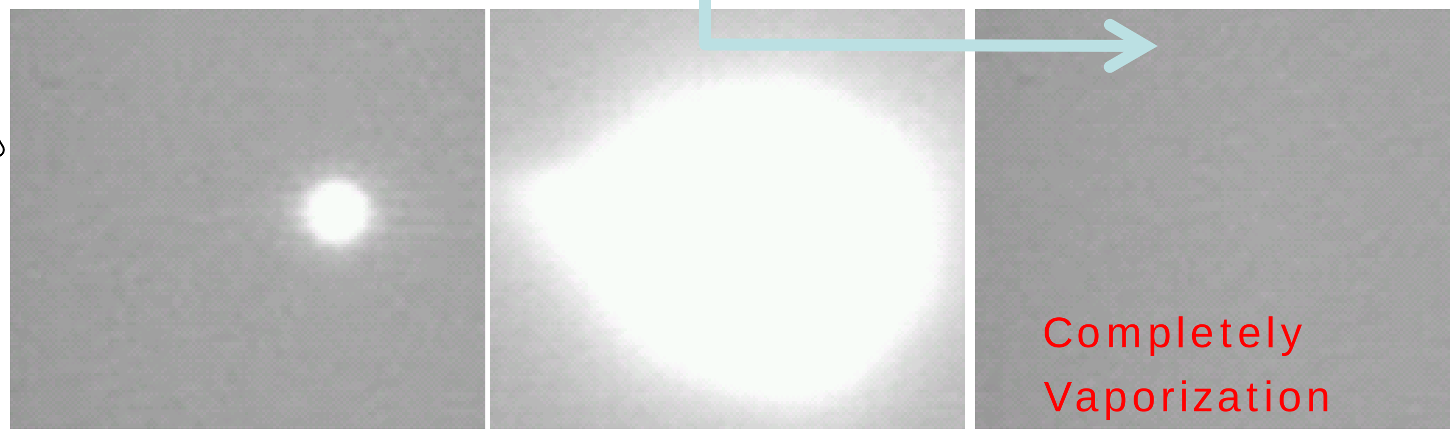
pre-pulse irradiation — Main pulse laser / EUV emission — after EUV emission — Time

a) without main-pulse laser



b) with main-pulse laser

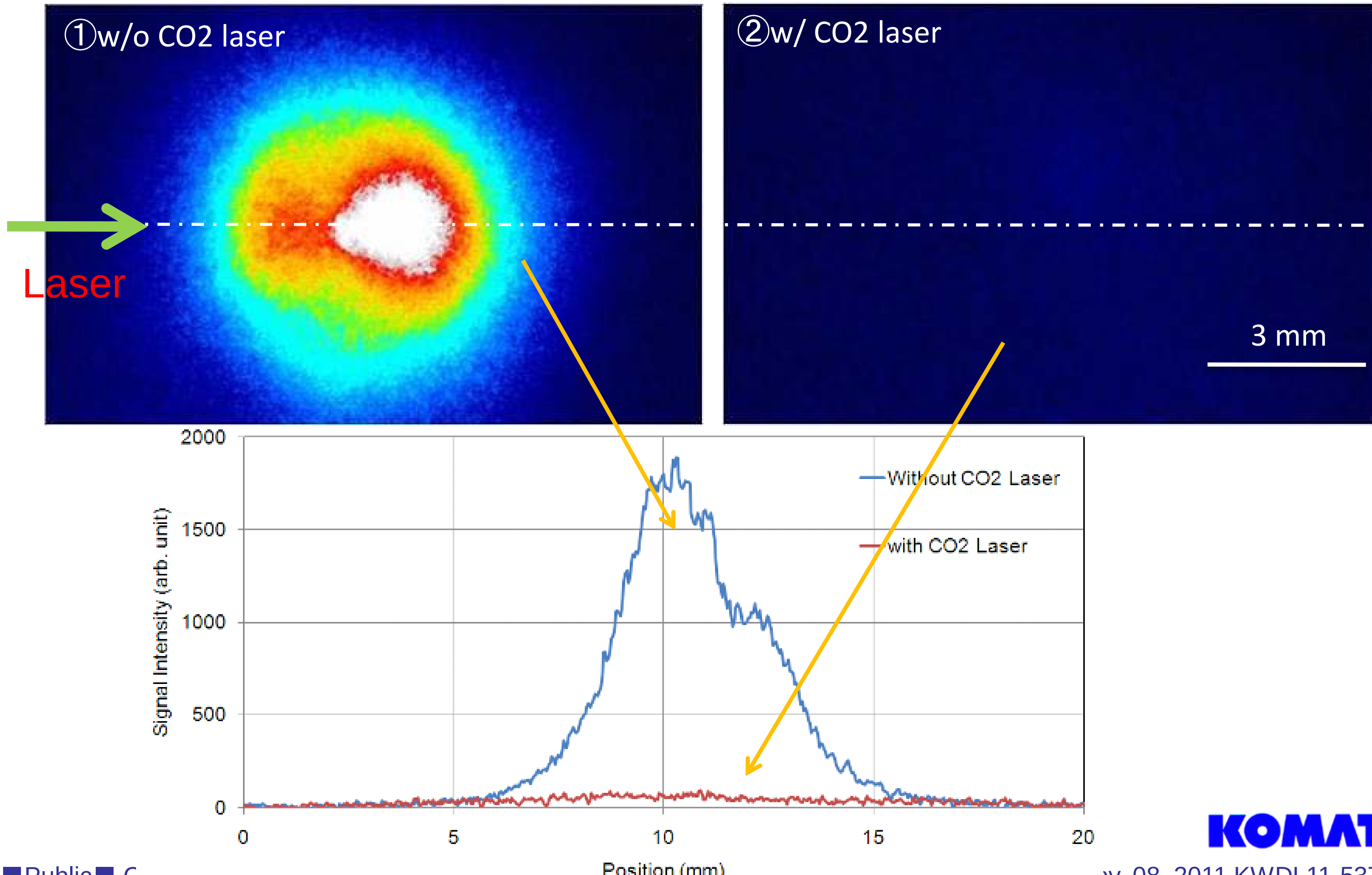




Sn Atom Measurement by LIF

13.5nm

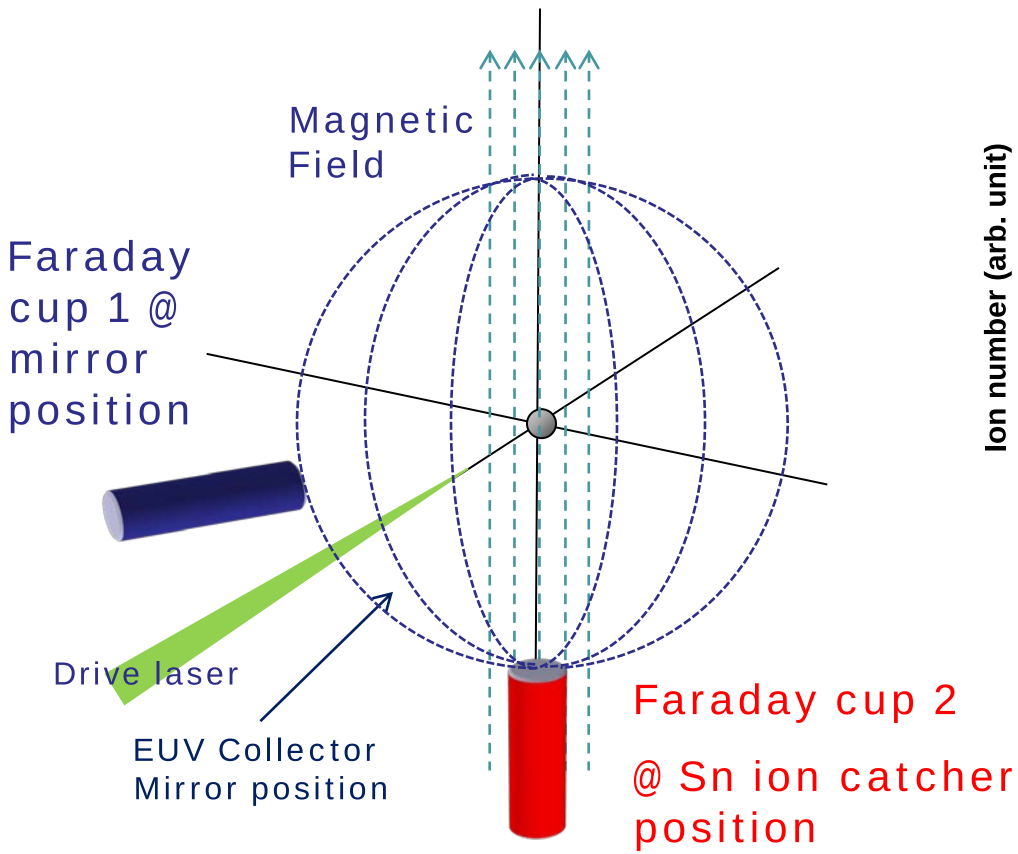
Remaining atoms was estimated by subtracting w/ CO_2 vs. w/o CO_2 measurement

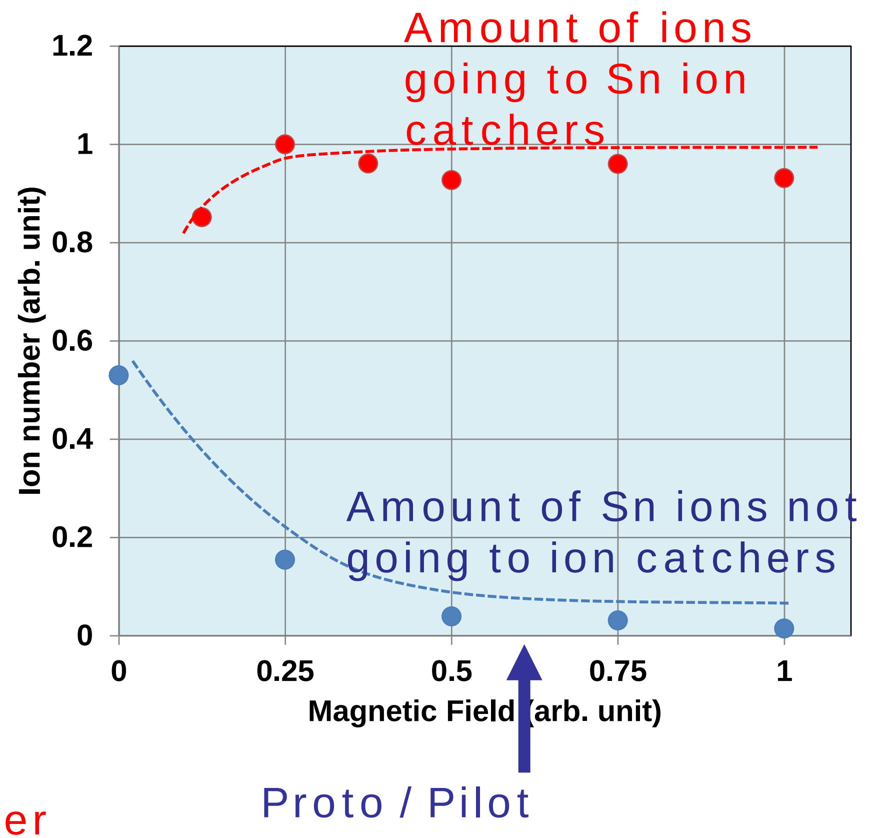


Sn Ion Measurements by Faraday Cups

13.5nm

- Amount of ion is measured by Faraday cup

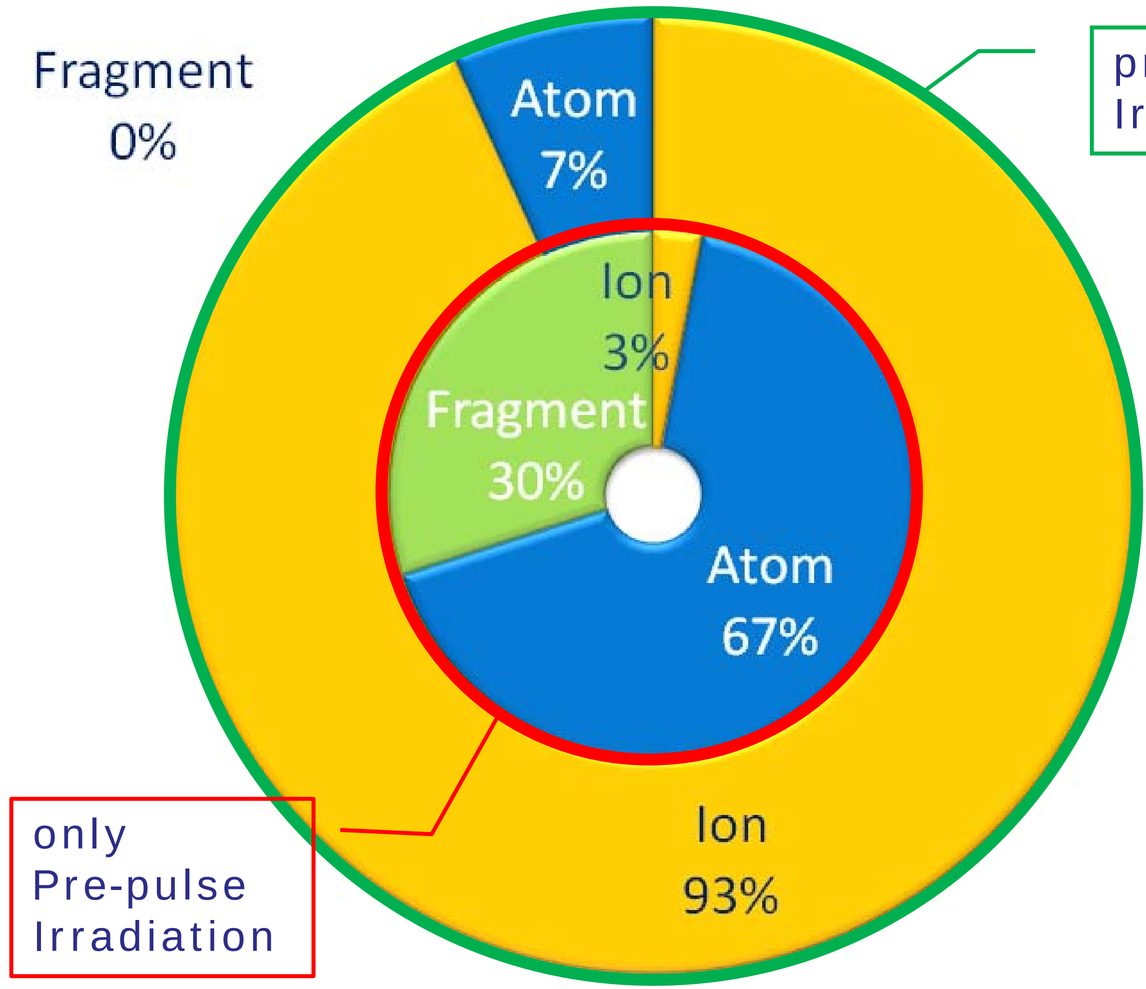




Sn Mitigation : Results Summary

13.5nm

- Sn molecule measurement results
  - ✓ pre-pulse laser + CO2 laser irradiation : ionized 93% of Sn
  - ✓ Only pre-pulse laser irradiation : ionized 3% of Sn



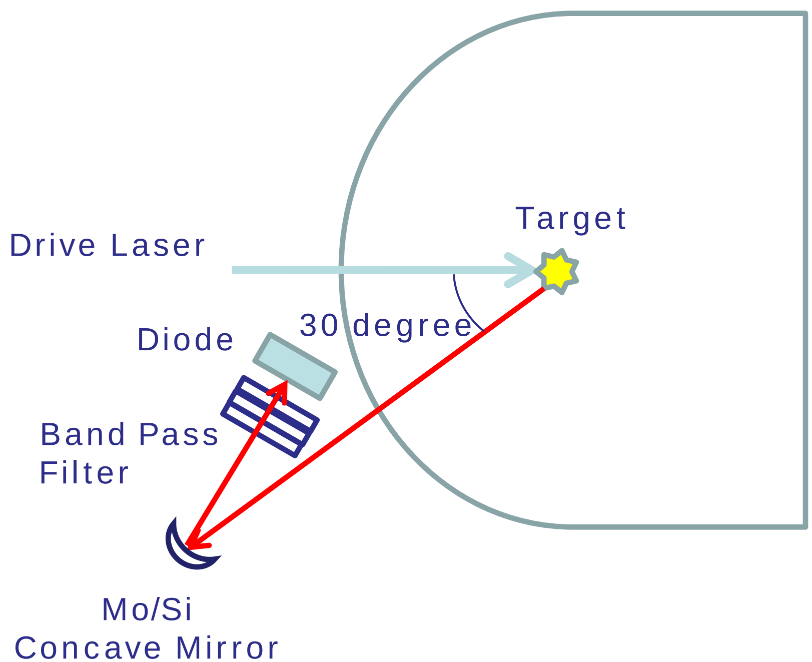
Experimental Condition:
Same as proto machine

		This time	Proto Condition
Repetition rate	Hz	10	100k

CE Improvement : Experimental Setup

13.5nm

- Metrology system
  - ✓ Flying circus with optics for 13.5 nm



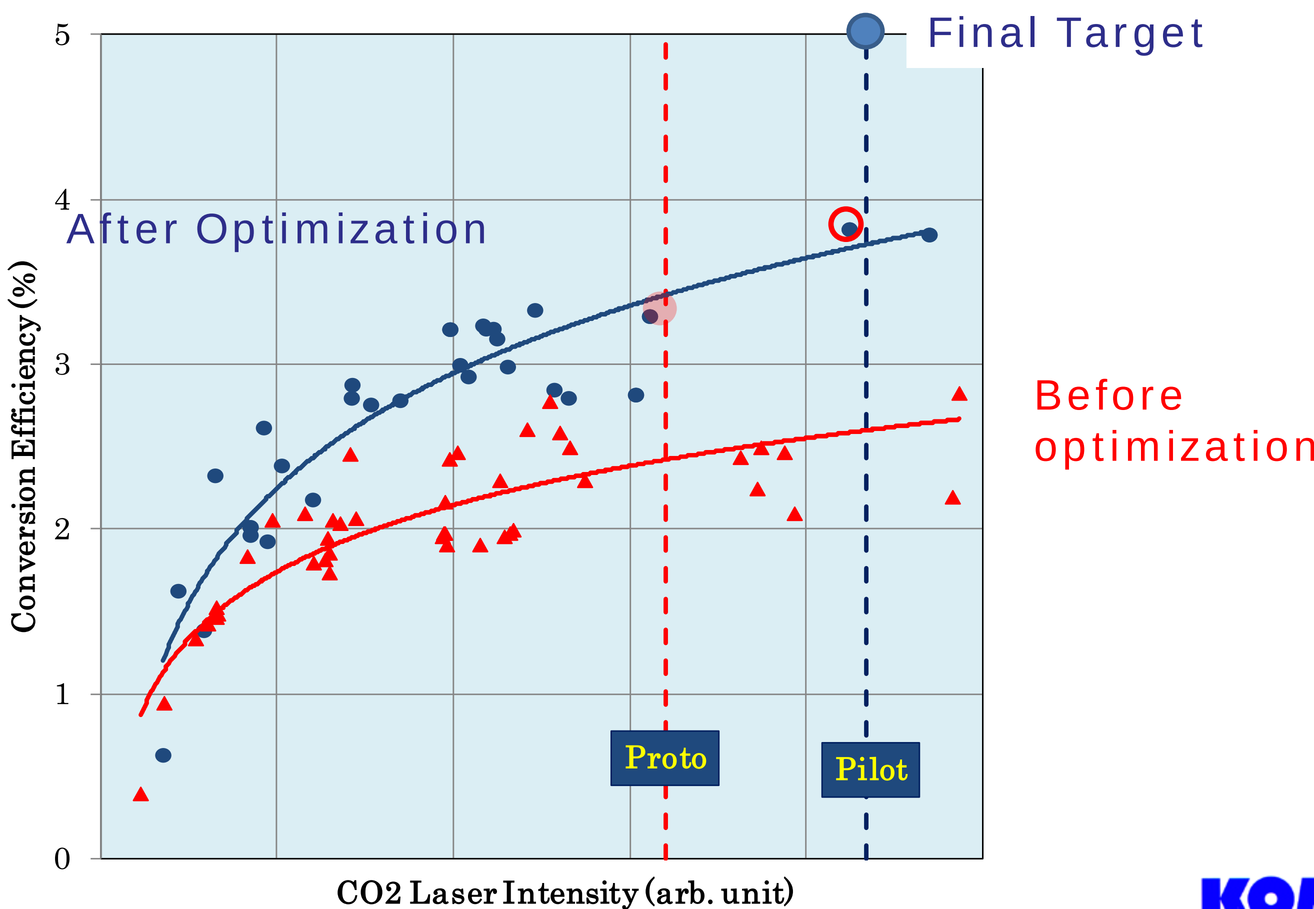
Drive laser Wavelength	um	10.6
Energy	mJ	~270
Repetition rate	Hz	~10
Target	Material	Tin
	State	20 um Droplet
Mirror	Layer Material	Mo/Si
Filter	Material	Zr
Diode	Material	Si photo diode

KOMATSU

Conversion Efficiency : 13.5nm
New champion data of CE = 3.8% (Aug.2011)

- After CE optimization
  - ✓ 3.3% → 3.8% (@ pilot condition)

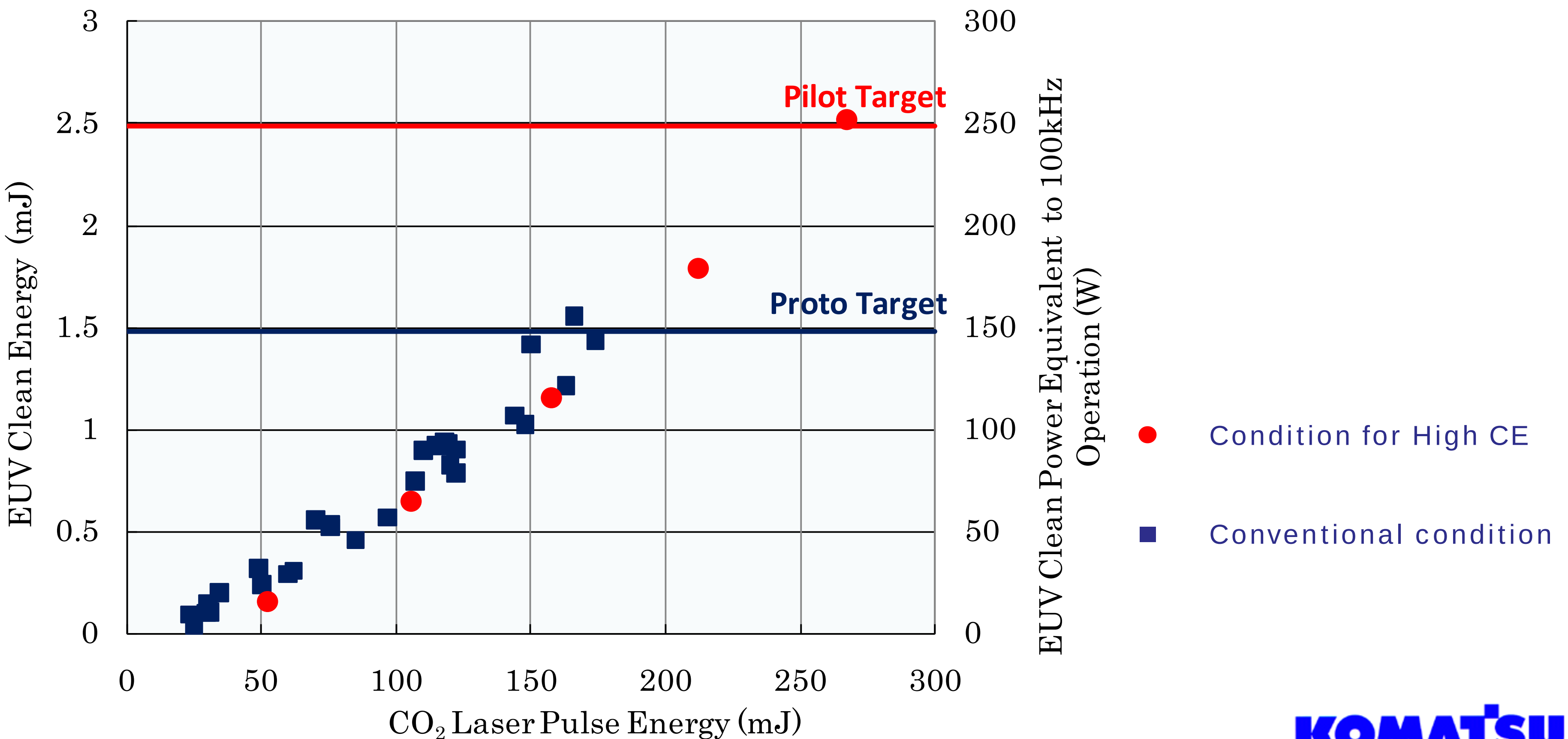
Conversion Efficiency vs. CO_2 Laser Intensity



EUV Output Power : vs. CO2 Input Power

13.5nm

- Achieving 2.5mJ EUV output which correspond to 250W clean power in test rig
  - ✓ With regarding estimated loss from plasma to Intermediate Focusing point



6.x nm EUV experiential results on test rig

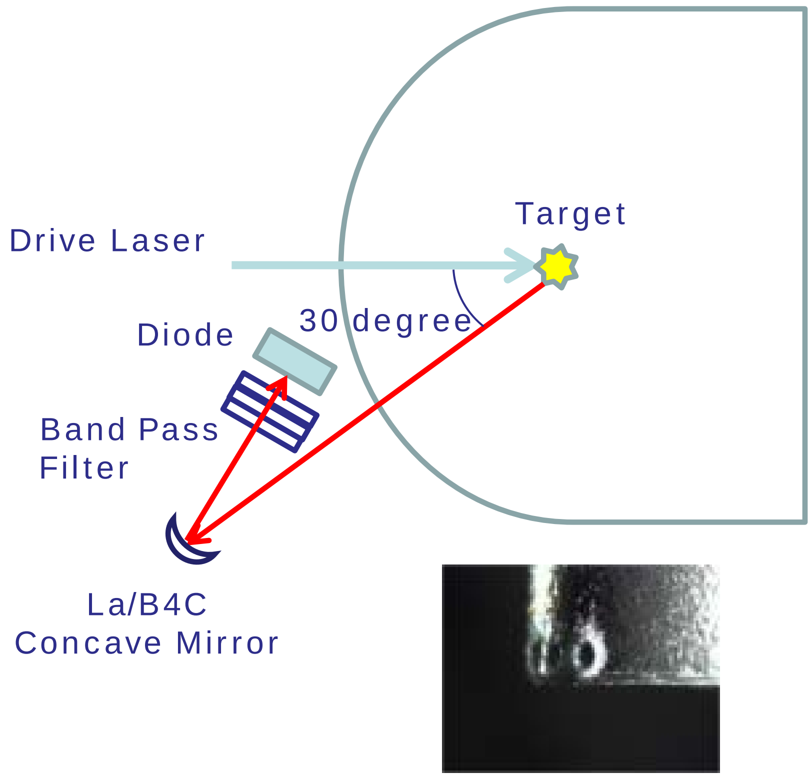
Laser wavelength dependence

Results comparison with 13.5nm results

Experimental Setup for 6.7 nm EUV Test

6.x nm

- EUV generation Experiments with different wavelength
  - ✓ Using two kind of laser



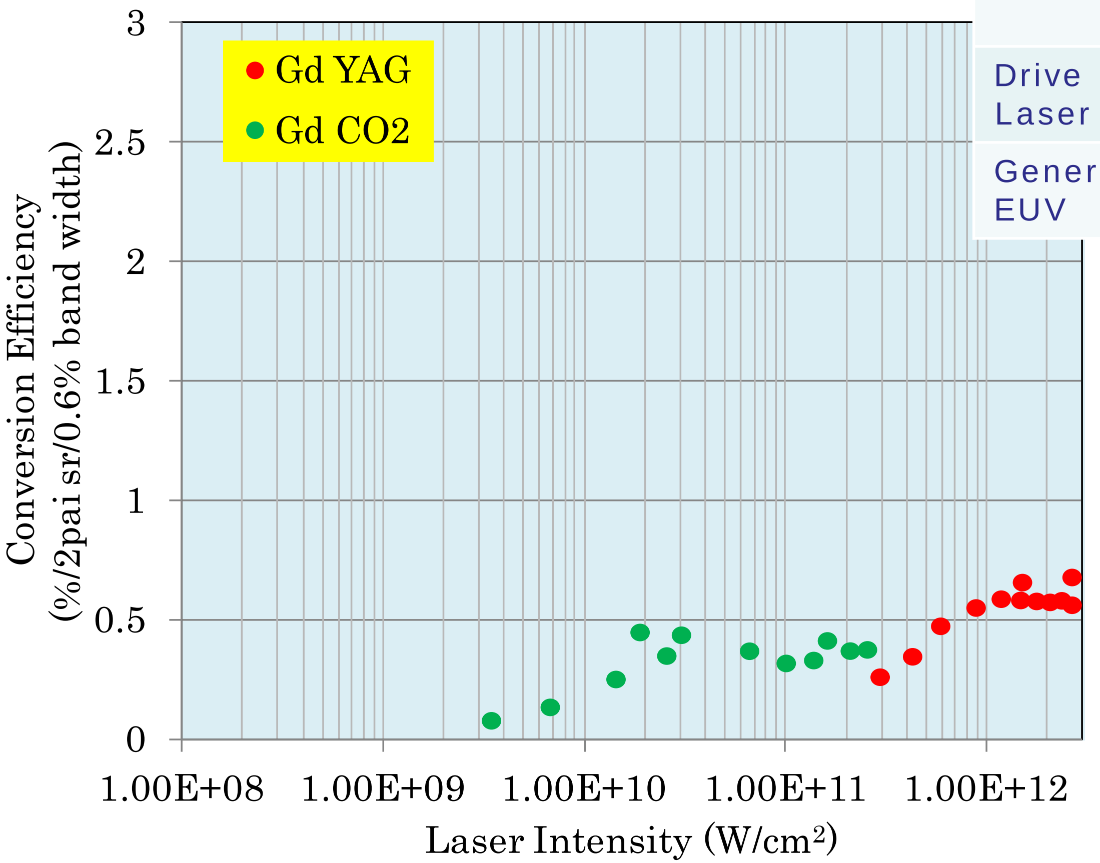
		YAG	CO2
Drive laser Wavelength	um	1.064	10.6
Energy	mJ	~900	~185
Intensity	W/cm^2	$\sim 10^{12}$	$\sim 10^{11}$
Repetition rate	Hz	~10	~10
Target	Material	Gadolinium	
	State	Bulk **φ12.5mm** column	
Mirror	Layer Material	La/B4C	
Filter	Material	Zr	
Diode	Material	Si photo diode	

KOMATSU

Results : Gd excitation for 6.7nm emission 6.x nm

- CO2 laser : Needed lower intensity to generate 6.x nm compared to YAG laser
- YAG laser : higher CE with this configuration

			Gd CO2	Gd YAG
Target	Material		Gado-linium	Gado-linium
	State		Bulk	Bulk
Drive Laser	Wave-length	nm	10.6	1064
Generated EUV	Wave-length	nm	6.7	6.7



Speculation :
EUV Emission
Isotropic Radiation

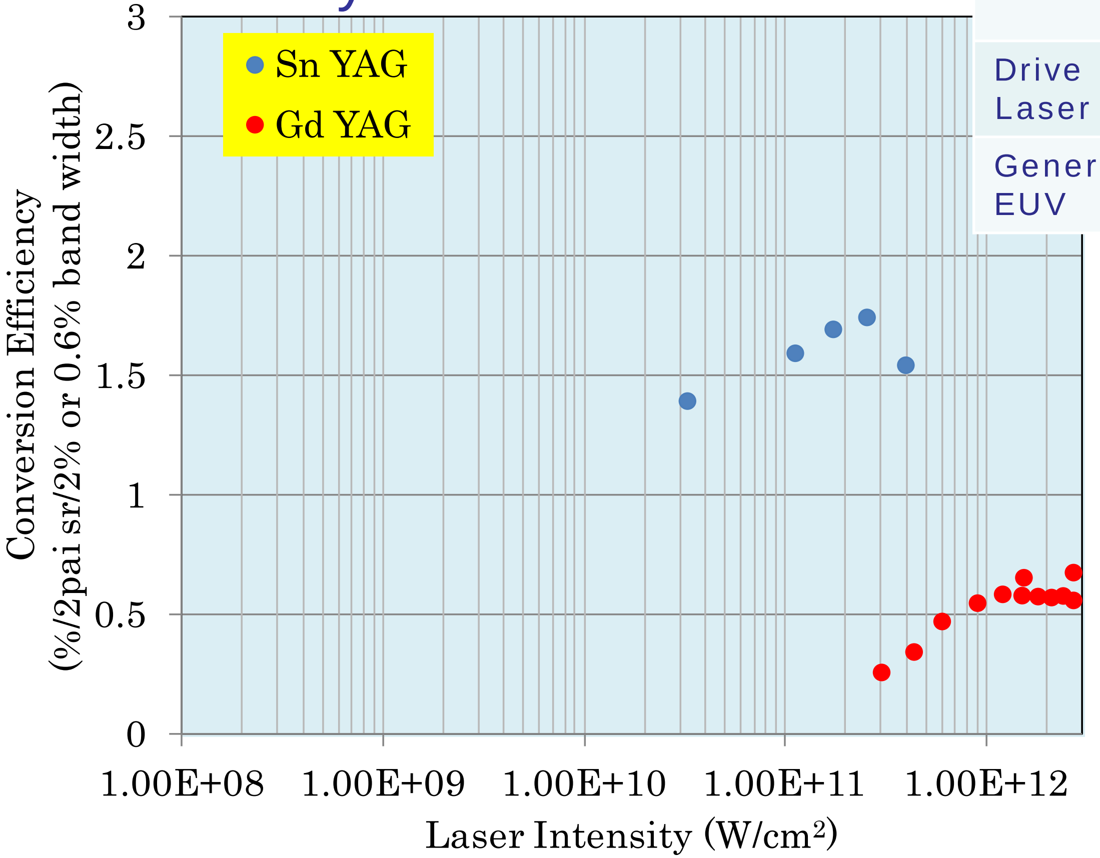
KOMATSU

Results : YAG Laser Excitation

6.x nm
13.5 nm

- Smaller CE of 6.7nm compared to 13.5nm
- Needed more drive laser intensity
- Saturated CE to laser intensity

			Sn YAG	Gd YAG
Target	Material		Tin	Gado-linium
	State		Bulk	Bulk
Drive Laser	Wave-length	nm	1064	1064
Generated EUV	Wave-length	nm	13.5	6.7



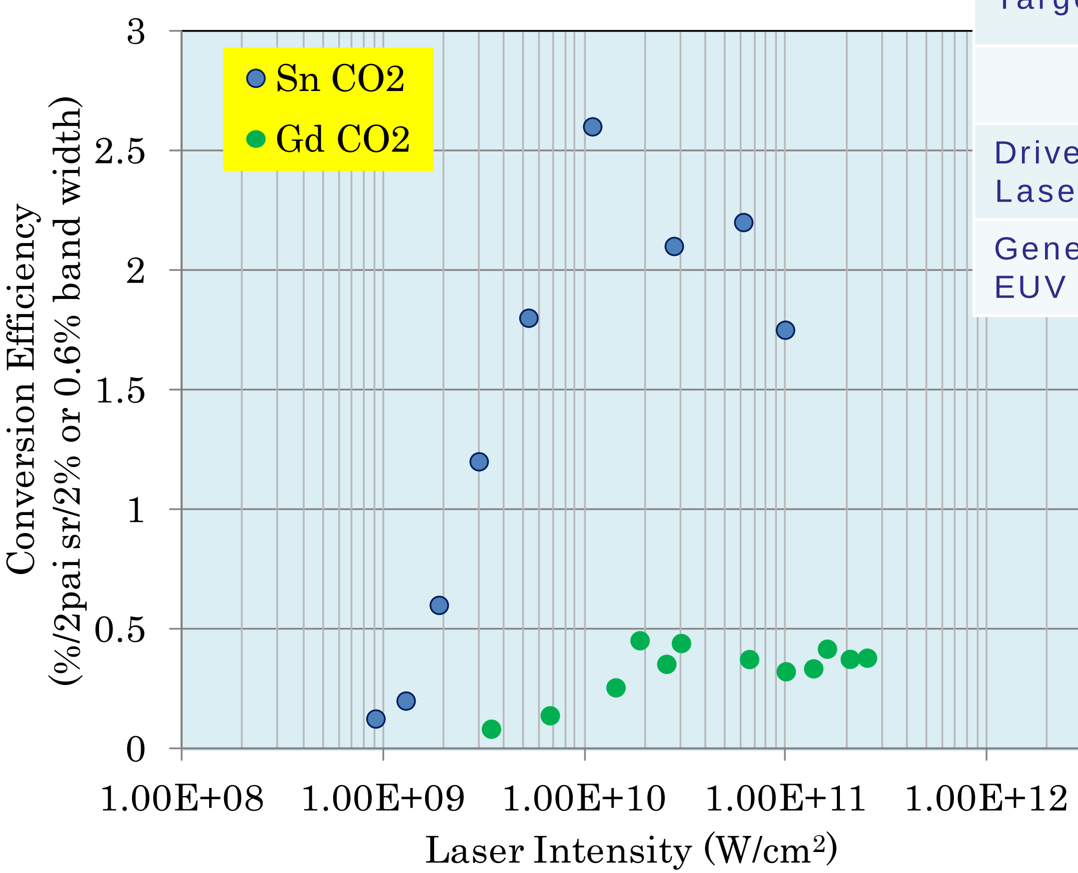
Speculation :
EUV Emission
Isotropic Radiation

KOMATSU

Results : CO2 Laser Excitation

6.x nm
13.5 nm

- Smaller CE for 6.7nm compared to 13.5 nm EUV
- Needed Intensity : same order for 13.5 nm & 6.7 nm



			Sn CO2	Gd CO2
Target	Material		Tin	Gado-linium
	State		Bulk	Bulk
Drive Laser	Wave-length	um	10.6	10.6
Generated EUV	Wave-length	nm	13.5	6.7

Speculation :
EUV Emission
Isotropic Radiation

KOMATSU

Summary : Wavelength Comparison

6.x nm

Larger YAG laser intensity (X100) compared to CO_2 laser for CE ~ 1% of 6.7 nm generation

		CO2	YAG
Target	Material	Gd	
	State	Bulk	
Center wavelength	nm	6.7	
Mirror reflection bandwidth	nm / %	0.05 / 0.8	
Max Conversion Efficiency	%/2πsr 2% or 0.6% BW	0.45	0.68
	mJ/2πsr 2% or 0.6% BW	0.83	6.1
Drive Laser Laser Energy	mJ	185	900
Wavelength	um	10.6	1.06
Needed Laser Intensity	W/cm^2	$\sim 10^{10}$	$\sim 10^{12}$

KOMATSU

Summary : Target Comparison with CO2 laser 6.x nm

Same order laser intensity of CO2 laser excitation for CE ~ 1% of 6.7 nm generation compared to 13.5 nm

		CO2	CO2
Target	Material	Gd	Sn
	State	Bulk	Bulk
Center wavelength	nm	6.7	13.5
Mirror reflection bandwidth	nm / %	0.05 / 0.8	0.5 / 4
Max Conversion Efficiency	%/2πsr 2% or 0.6% BW	0.45	2.6
	mJ/2πsr 2% or 0.6% BW	0.83	0.78
Drive Laser Laser Energy	mJ	185	30
Wavelength	um	10.6	10.6
Needed Laser Intensity	W/cm^2	$\sim 10^{10}$	$\sim 10^{10}$

Summary : Target Comparison with YAG laser 6.x nm

X 10 for YAG laser excitation for CE ~ 1% of 6.7 nm generation compared to 13.5 nm

		YAG	YAG
Target	Material	Gd	Sn
	State	Bulk	Bulk
Center wavelength	nm	6.7	13.5
Mirror reflection bandwidth	nm / %	0.05 / 0.8	0.5 / 4
Max Conversion Efficiency	%/2πsr 2% or 0.6% BW	0.68	1.7
	mJ/2πsr 2% or 0.6% BW	6.1	6.0
Drive Laser Laser Energy	mJ	900	350
Wavelength	um	1.06	1.06
Needed Laser Intensity	W/cm^2	~10^{12}	~10^{11}

KOMATSU

Discussion

6.7 nm

- Comparison between 6.7nm excitation and 13.5nm,
- Needed laser intensity
  - X10 higher Intensity with 1.06um laser excitation
    - May due to necessary of higher temperature to excite 6.7nm EUV
  - Same order with 10.6um laser excitation
    - Same mechanism for Sn+CO2 laser?
- Optics : Cause of low CE
  - May due to narrower reflection bandwidth of mirror
  - May insufficiently tuned mirror reflection spectrum to a radiation spectrum
    - For YAG Excitation OK, but for CO2 excitation NOK?

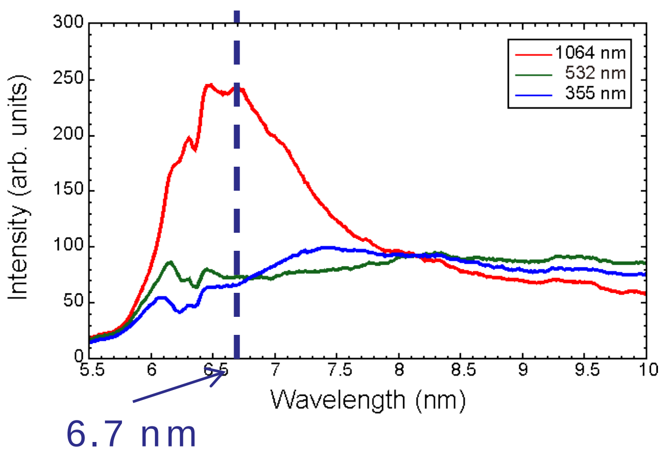
Reference : Radiation Spectrum of Gd by YAG excitation 6.x nm

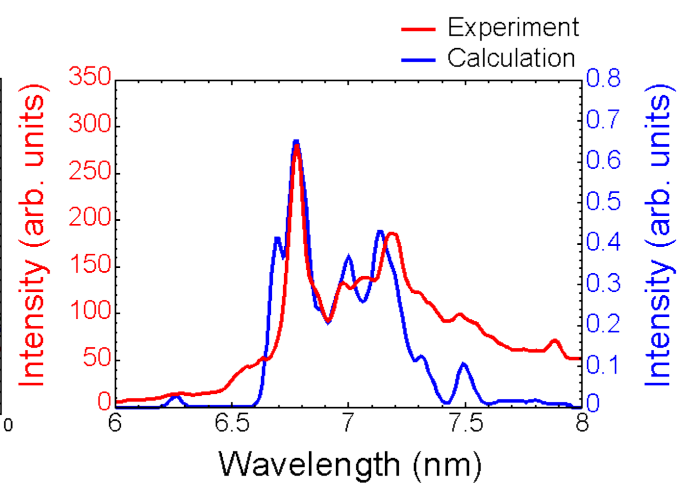
What's new

for high power and high CE

- Laser color dependence
- Resonant line appearance in low-density plasma
- Enhancement condition of the 6.7-nm emission

Broad band in 6~7 nm





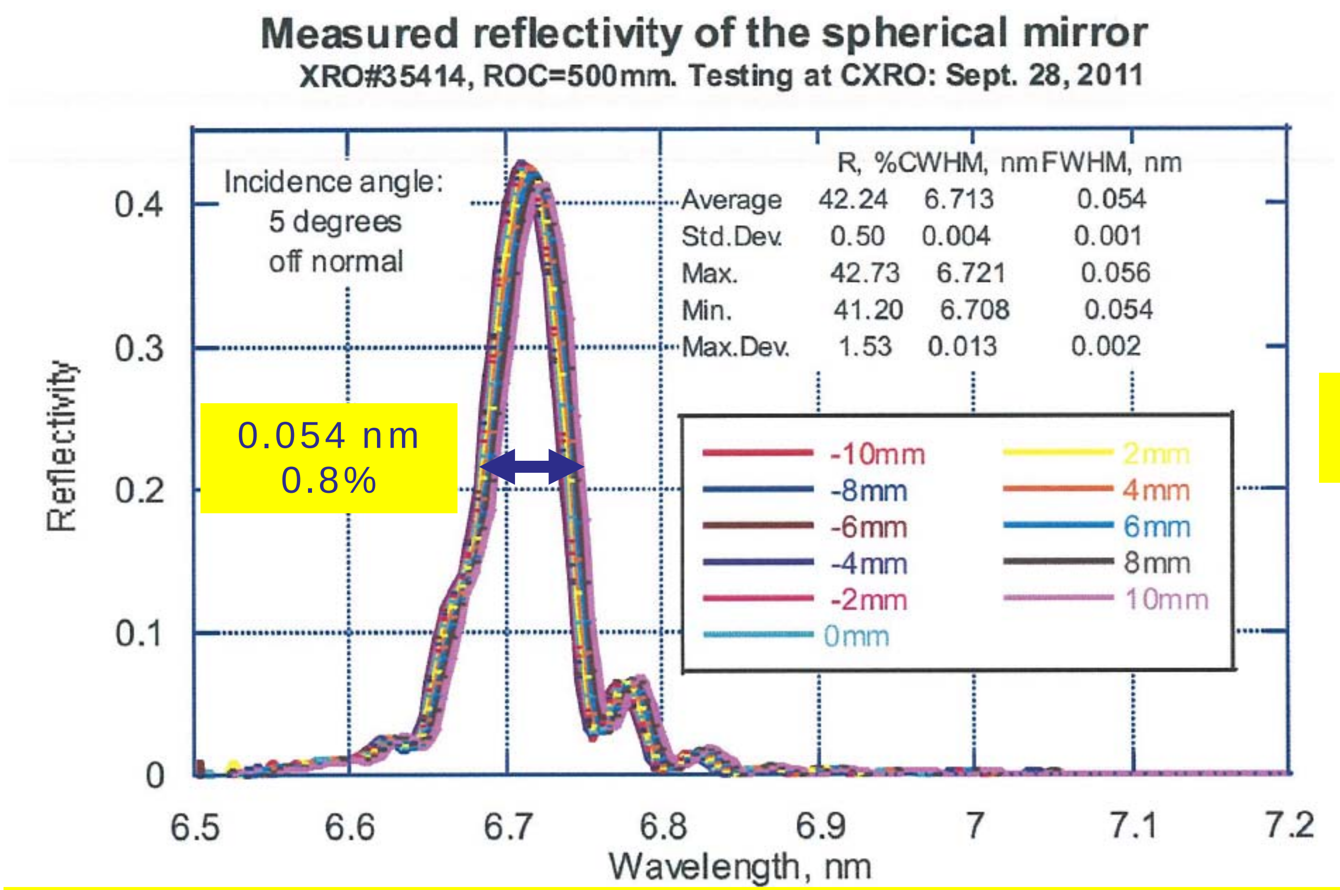
Takeshi Higashiguchi, Utsunomiya univ. 2011 International Workshop on EUV Lithography, Maui, Hawaii, USA, 2011

KOMATSU

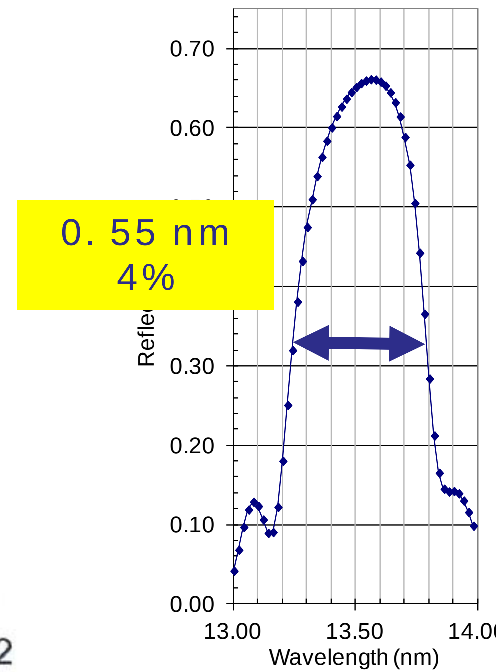
Experimental setup : Mirror Reflectivity

6.x nm

- LaB4C multilayer
- Narrow band reflectivity compared to 13.5nm mirror
  - ✓ Band width 0.8%, 0.054nm (FWHM)



Mo/Si mirror for 13.5nm



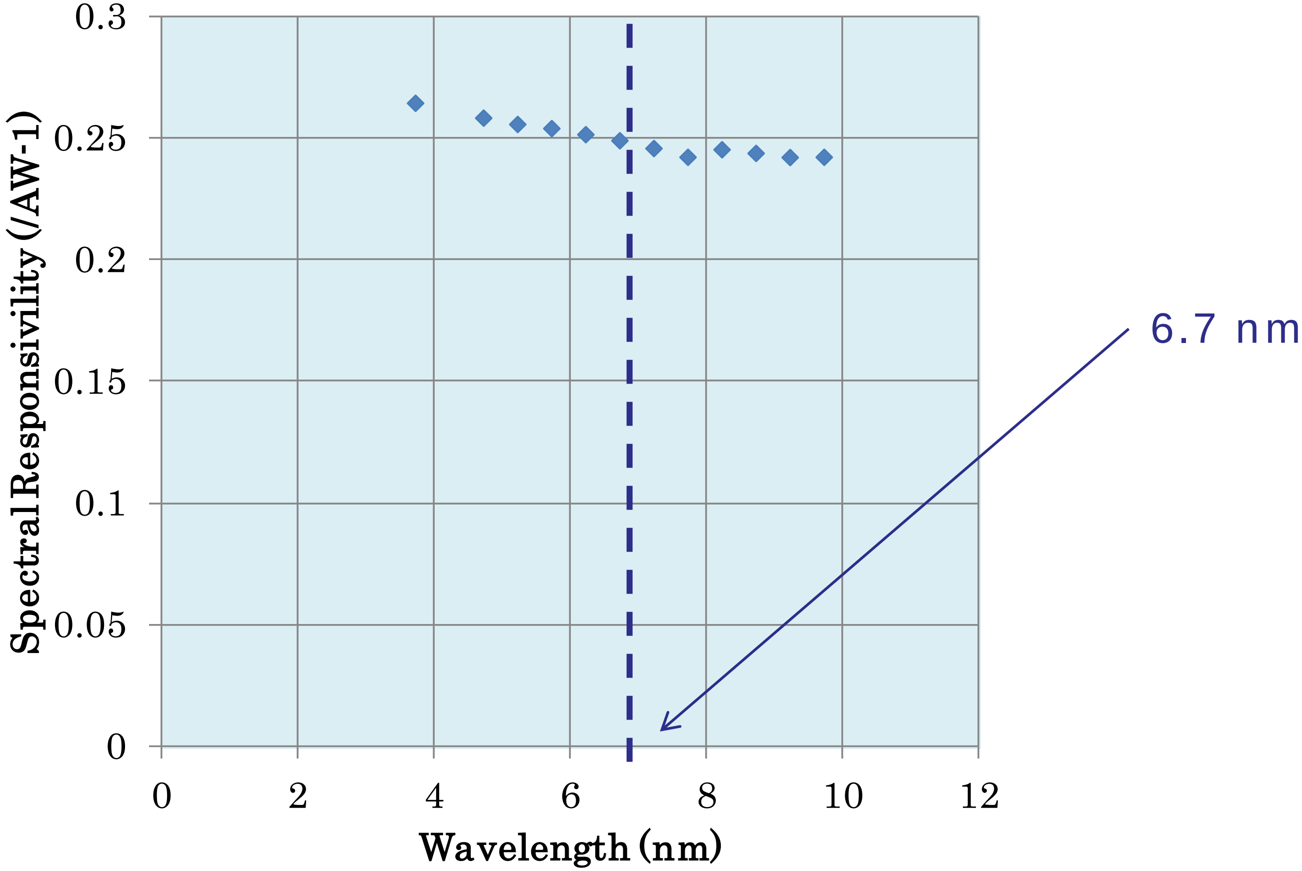
Manufactured by Rigaku Innovative Technologies, Inc.
Inspected by CXRO Lawrence Berkeley National Lab.

KOMATSU

Experimental : Diode Detector Sensitivity

6.x nm

- Silicon p-n junction photodiodes
  - ✓ Broad band sensitivity in 6.7 nm region

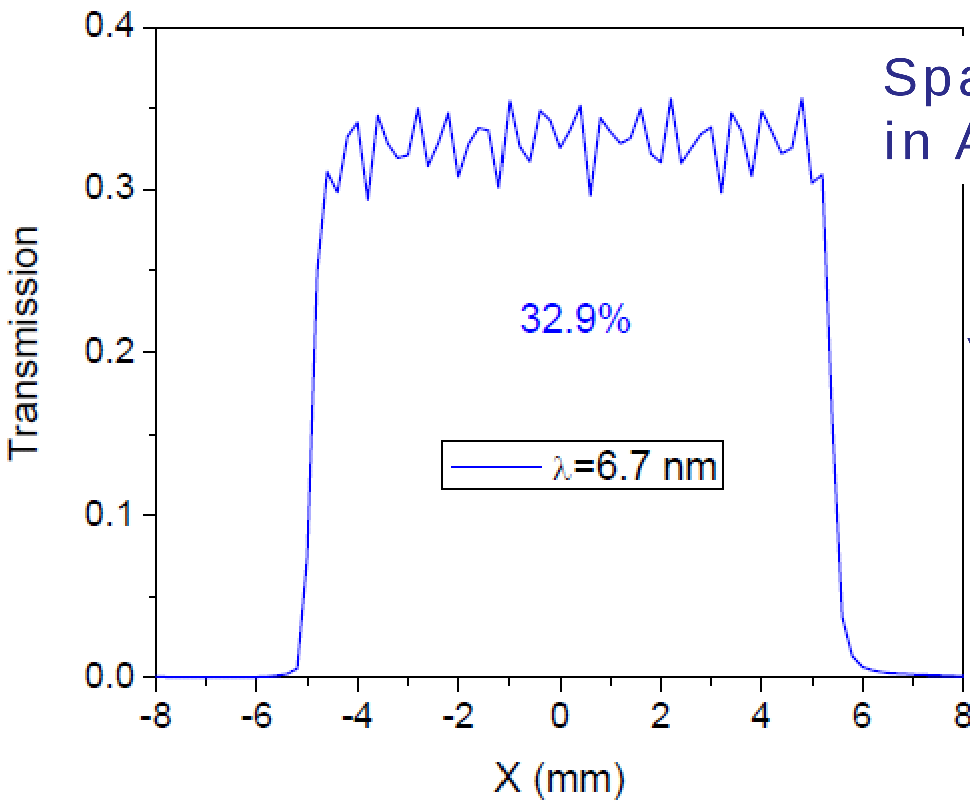


Manufactured by Opto Diode Corporation(IRD)
Inspected by PTB (Physikalisch-Technische Bundesanstalt)

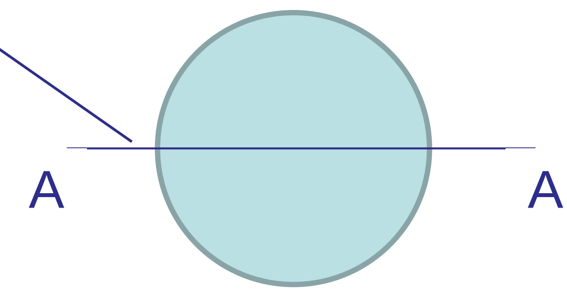
KOMATSU

Experimental : Band Pass Filter Transmission 6.x nm

- Zirconium Filter
  - ✓ Uniform spatial distribution



Spatial distribution
in A-A' cross section



Zr filter

Manufactured by LUXEL Corporation
Inspected by CXRO Lawrence Berkeley National Lab.

Conclusions

6.x nm

Laser intensity

- CO2 laser excitation preferable with regard to development
- Needed higher laser intensity for CE ~ 1% of 6.7 nm generation compared to 13.5 nm
  - ✓ >X 10 for YAG laser excitation
  - ✓ Same order (>X 2) for CO2 laser excitation

Optics

- Needed reflection spectrum tuning to radiation spectrum
  - ✓ OK : YAG laser excitation
  - ✓ ?? : CO2 laser excitation

Comments

6.x nm

- We will further investigate target state, structure for higher CE

- Relatively higher CE reported in other work on 6.x nm EUV emission
  - ✓ Utsunomiya University (S40)
  - ✓ Osaka University (S29)
  - ✓ ISAN (S35)
- Possibility for higher CE by optimization of target
  - ✓ Foil target of ISAN
  - ✓ Porous target of Utsunomiya
  - ✓ Non optimized bulk target on this work

Thus,

- Key technology for higher efficiency
  - ✓ Target state
  - ✓ Target supplying method

Future work

- Further measurements for 6.x nm EUV emission by LPP
  - ✓ Spectroscopy of radiation for optimization to collect EUV light efficiently
  - ✓ Spatial distribution of EUV radiation
  - ✓ More detailed drive laser property investigation for higher EUV radiation

Next Step,

- Target study
  - ✓ Supplying method for continuous operation
  - ✓ Molten Gadolinium?

Acknowledgments

Authors appreciate the useful discussion with and advices from,

Prof. Akira Endo, Waseda University
Prof. Takashi Higashiguchi, Takamitsu Otsuka, Utsunomiya university

Gigaphoton's mission is to be the No.1 provider of advanced technology and quality products, and to contribute to society as the industry leader.

We at Gigaphoton aim at being a team of professionals who can build a strong relationship of mutual trust, both within and outside of the company.

GIGAPHOTON

http://www.gigaphoton.com